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Preliminary Assessment of a Biogas-Based Power Plant from Organic Waste in the North Netherlands

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Abstract: Biogas is expected to play a crucial role in achieving the energy targets set by the European Union. Biogas, which mainly comprises methane and carbon dioxide, is produced in an anaerobic reactor, which transforms biomass into biogas. A consortium of anaerobic bacteria and archaea produces biogas during the anaerobic digestion (AD) of various types of feedstocks, such as animal slurries, energy crops, and agricultural residues. A biogas-fed gas turbine-generator and steam generator produce heat and power. In this study, a combined heat and power installation is studied. The biogas-based power plant treating cow manure, grass straw, and sugar beet pulp was examined using the software SuperPro Designer, and the obtained economic reports are evaluated. From the results, subsidy for electricity does not change the feasibility of the plants in case that cow manure or sugar beet pulp are used as feedstocks. The net present value (NPV) of biogas plants treating cow manure and sugar beet pulp was negative and the subsidy is not sufficient to make profitable these cases. The biogas power plant treating straw showed a positive net present value even without subsidy, which means that it is more desirable to invest in a plant that produces electricity and digestate from grass straw.

Keywords: anaerobic digestion; organic residues; biogas plant; CHP unit; net present value

1. Introduction

In recent years, energy demands have increased rapidly all over the world and new technologies are required to address this issue [1–6]. The limitations of fossil fuel resources and their adverse effects on the environment have led to increasing interest in the use of renewable energy resources, including biogas, a combustible gas which mainly consists of methane and carbon dioxide [7–14]. By 2030, the EU aims to have at least a 40% greenhouse gas emissions (GHG) reduction and increase the use of renewable energy by 27% [15]. AD is used to convert biomass or biowaste for biogas production [16–19]. Biogas plants can play a significant role in the reduction of (GHG) [20]. Several research efforts have been made to improve the efficiency of biogas plants and examine the sustainability aspect of biogas production [21–26]. Continuous improvement of biogas plants operation has mainly applied on the process steps, i.e., pretreatment, or operating conditions (temperature, pH, etc.), however, optimization at a biological level by enhancing the microbiome of the reactor has also attracted the interest of researchers [27–29]. The choice of pretreatment is very critical for viability of the biogas power plant [30–32]. Rosero-Henao et al. [33] reported that critical and supercritical pretreatment of lignocellulosic biomass redounded the enhancement of AD. Luo et al. [34], by reviewing the metabolomic pathways in two-stage AD, concluded that understanding of the microbial dynamics is intrinsic for the smooth operation of the reactors and depends on the equipment configuration. Biogas produced from lignocellulosic waste in a biogas installation can be used for electricity generation using different techniques [35–37]. However, currently heat and energy production using a combined heat and power (CHP) unit is the most common application for energy recovery from biogas [38–40] and the efficiency of a CHP unit, after the compression, is 90% and it produces 65% heat and 35% electricity [41,42].

This study assesses the biogas-based heat and power generation from cow manure (CM), grass straw (GS), and sugar beet pulp (SBP). These three types of feedstock can be widely found in many agro-industrial regions. Most dairy cattle in the Netherlands can be found in the northern provinces Groningen, Friesland, and Drenthe [43]. In 2017, the number of cows was approximately 108,000 in Groningen, 307,000 in Friesland, and 113,000 in Drenthe [44]. Due to the wide availability and the revenue aspect for biogas plants, CM is an important type of biomass in the north of the Netherlands. Besides CM, SBP is another type of biomass which is investigated in this research (Table 1). In 2018, 29,510 hectares were used to grow sugar beets with an average yield of 74 ton per hectare [45]. In the processing of one ton of sugar beet, approximately 500 kg pulp is generated [46]. SBP is widely available within the north of the Netherlands. The purchase price for SBP is 14 €/ton [46] Moreover, GS is also examined for biogas production. GS is widely available in the north of the Netherlands, and more land can become available for the production of this type of biomass [47]. In 2017, the total harvest of GS was 2.4 ton/ha. The total area of grass in the north of the Netherlands that is harvested is approximately 933,020 ha [48].

The goal of this study is to compare the profitability of a biogas power plant located in the North Netherlands treating CM, GS, and SBP and examine the potential for bioenergy applications of GS and SGP as substrates compared to conventional substrate CM. Technical analysis is carried out on the basis of amount and composition of the substrates, biogas yield, electricity and heat generation and consumption of biogas plant. Economic performance of the systems has been carried out on the basis of net present value (NPV) and internal rate of return (IRR). This study provides techno-economic information to a broad audience and can also be used as a reference for further business investigation for the North Netherlands as well as for regions where similar biowaste are available. The paper is structured as follows: Section 2.1 introduces the types of biowaste used for study and Section 2.2. describes process equipment and data used, and assumptions made for designing the plant. Section 3 contains the results of the study. The final section presents our basic conclusions.

2. Materials and Methods

2.1. Feedstocks

It is assumed that the biogas plant operates 335 days (92%) a year and 24 hours a day. Organic biomass is fed into the reactor with a constant supply of 10,000 tons per year. This means that in the modeling part, the input rate is 1243.8 kg/h. It is essential to investigate the amount of feedstock that can be obtained from the local region. In this study, three different types of lignocellulosic biomass are investigated, resulting in the modeling of three separate cases in SuperPro Designer (Intelligen, New Jersey, USA).

Table 1. Composition of CM, SBP and GS based on wet weight [49–51].

Ingredient	CM	SBP	GS
	Mass %	Mass %	Mass %
Ash	2.3	5.1	8.9
Cellulose	4.8	15.1	28.
Hemicellulose	4.1	18.2	18.80
Lignin	3.0	0.9	11.4
Lignin soluble	-	-	2.0
Proteins	2.3	10.3	-
Protein soluble	-	-	4.7
Extractives	3.8	-	18.0
Water	79.6	29.6	7.0
Fats	0.1	-	-

CM is one of the feedstock types for biogas production. One cow, with a typical weight of 635 kg, generates 23 wet tons of manure annually. Moreover, farmers have to pay to get rid of their CM. The price of CM is set at 0.03 €/kg and can be considered as revenue for the biogas plants. Besides CM, SBP is another type of biomass which is investigated in this research. In the processing of one ton of sugar beet, approximately 500 kg of pulp is generated [46]. Moreover, GS is also examined for biogas production.

2.2. Process Design

After collecting the relevant data, the cost and revenues of a biogas power plant are calculated. SuperPro Designer [52] is a program that designs the different production processes of an industrial plant. After designing the processes and filling in the required data as input in SuperPro Designer, the cost and income are calculated. Figure 1 presents an overview of the biogas plant.

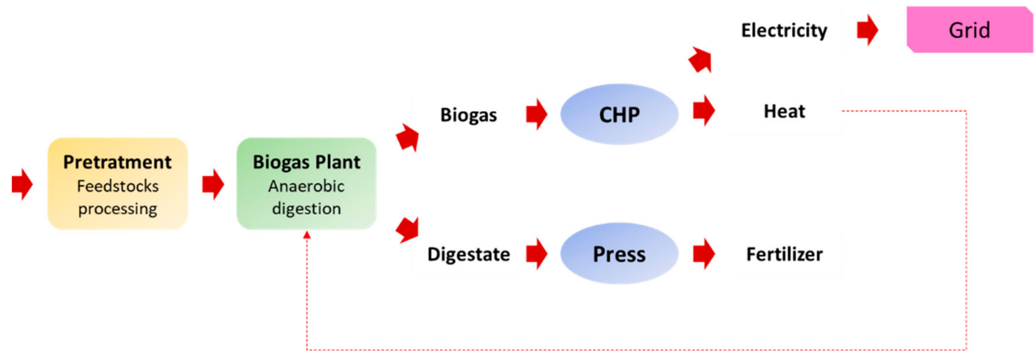

Figure 1. Schematic overview of the biogas-based power plant.

Hereafter, the viability of a biogas power plant can be evaluated in terms of net present value (NPV), internal rate of return (IRR), and payback period (PP). During the design of the biogas plant in SuperPro Designer, several process parameters and technical specifications are needed. These parameters and specifications are obtained from literature data. However, some parameters of the plant cannot be found and, therefore, assumptions were made. The biogas power plant were simulated within SuperPro Designer to obtain financial results. The system is divided into three stages: biogas production plant, CHP unit, and digestate processing.

2.2.1. Biogas Production

In this stage, biogas is produced from raw material in an anaerobic reactor. The organic waste is transported from the delivery truck to a grinder using a conveyor belt. It is assumed that the length of the conveyor belt is 20 m from the truck to a grinder. Furthermore, it is assumed that feedstock is available throughout the whole year.

Therefore, it is not necessary to have a pit before the grinding equipment. The power needed for the conveyor belt and the grinder is 5.5 kW and 5.37 kW, respectively, values which are available from the equipment database in SuperPro Designer. After the grinding process, a centrifugal pump transports the ground feedstock into the reactor. The biological processes are performed at mesophilic conditions of 35 °C in a semi-continuous flow stirred tank reactor and with a hydraulic retention time of 600 h. The power needed for heating and stirring is 0.01 kW/m^3. The reaction conversion efficiency of proteins, cellulose, hemicellulose, extractives and lignin from GS are 90%, 50%, 50%, 45%, and 50%, respectively [53]. It is assumed that the conversion efficiencies of the reactions that take place in the anaerobic reactorfor CM and SBP are similar to GS. As can be seen in Figure 2, a grinder is used after the conveyor belt. However, in the biogas production process of CM, a screw press is used instead of grinding equipment. Screw pressing equipment is used at the CM process since CM has a high percentage (79.60%) of water. Table 2 shows the main technical specification used in the simulation, with the equipment Unit ID used for the simulation of biogas production. Although SBP and GS have the same amount of biomass that flows into the reactor, the volumetric flow of SBP is higher compared to GS due to the composition. Therefore, more volume is needed for the reactor that uses SBP as feedstock.

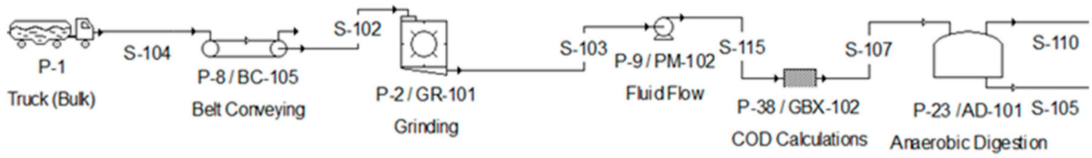

Figure 2. Process flow diagram of the biogas production in SuperPRO Designer.

Table 2. Main parameters that are used in the simulation of anaerobic digestion of CM, SBP, and GS.

Unit ID	Description	Details	CM	SBP	GS
P-8/BC-105	Belt conveying	Length (m)	20.0	20.0	20.0
P-2/SP-101	Screw press	Rated throughput (kg/h)	1243.8	-	-
P-2/GR-101	Grinder	Rated throughput (kg/h)	-	1243.8	1243.8
P-9/PM-102	Pump	Pump power (kW)	0.02	0.05	0.04
		Vessel power (kW/m^3)	294.7	749.9	692.3
P-23/AD-101	Anaerobic reactor	Residence time (h)	600	600	600
		Temperature (°C)	35	35	35

The amount of biogas that is produced from 1243.8 kg/h CM is 156.44 kg/h and consists approximately of 52.2% methane and 47.8% carbon dioxide. In Table 3, the input and output of the reactor are shown. The water concentration in the feedstock is the main reason for the difference in biogas yield of the AD. GS contains 7% water, whereas CM contains 79.6% and SBP contains 29.6%. Therefore, more dry matter per hour is available in SBP and in GS to convert to biogas.

Table 3. The input and output of stage 2 for the feedstocks CM, SBP, and GS.

Unit ID	Input	Output			
	Feedstock	Unit ID	Volume (kg/h)	Products	Volume (kg/h)
S-106	CM	S-121	337.3	Water	193.8
		S-119		Residues	143.5
S-106	SBP	S-121	852.1	Water	266.3
		S-119		Residues	585.7
S-106	GS	S-121	800.9	Water	4.5
		S-119		Residues	798.5

2.2.2. CHP unit

The main application of biogas in Europe is combined heat and power (CHP) production. Previous studies report the environmental and economic benefits from the application of CHP systems fed with biogas in comparison to fossil fuels [54–56]. Goulding and Power conducted techno-economic analysis of biogas CHP unit in Ireland and they observed optimal efficiency. Nevertheless, several parameters i.e., policy, technological substratum, economic landscape, are crucial for the biogas combustion [57]. A former study investigated multiple cases for the energy supply in Europe in 2015 [58]. They developed model was based on renewable resources consumption and they enunciated that biogas production has to increase at least 6 GW/year. Hamzehkolaei and Amjady also conducted financial assessment of biogas CHP installation and concluded to cost savings up to 65,000 € and CO_2 saving up to 530 ton [59]. Another study tested the biogas produced from the cow manure treatment in a farm-scale plant and resulted in emission yearly savings of 7500 ton CO_2 [60].

After the anaerobic digestion process, biogas can be simultaneously converted into heat and electricity in a CHP unit (Figure 3). Description of the reaction occurring in the combustion process is very difficult and out of the scope of this study as depends on many factors such as temperature, pressure, type of burner, the composition of the mixture of fuel and combustion oxidizing hydrocarbons, etc. The mechanism consists of a plurality of successive and overlapping reactions of various elementary reaction speeds. The removal of hydrogen sulfide and water from the fuel gas helps to optimize the combustion process in the engine and extends the lifespan of the engine [61].

The produced heat and electricity can be used in a biogas plant or it can be sold to be injected in the grid. Cogeneration is a widely used technique for power production from natural gas. After the anaerobic digestion process, biogas is compressed before it is burned in a gas turbine-generator. The turbine propels the compressor and the generator to produce power. The temperature of the exhausted gas is approximately 450 °C. During generation of electricity, steam generation equipment is used to capture the heat from the exhaust stream. This is done via input of air and water. Steam generation systems are very complex. However, modern control instrumentation makes the operation and control easier. The generated electricity is fed into the national grid, whereas the heat may be consumed internally, or via district heating networks, with typical transmission losses. In this study, efficiencies of the CHP unit were 36% for electricity and 45% for heat [60,61]. For this reason, conversion in two energy forms will be given by the equivalence; therefore, 1 m^3 of biogas produces hourly 2.0 kWh of electricity, and 2.5 kWh of heat energy considering the total energy value of biogas is 5.5 kWh/m^3 [60].

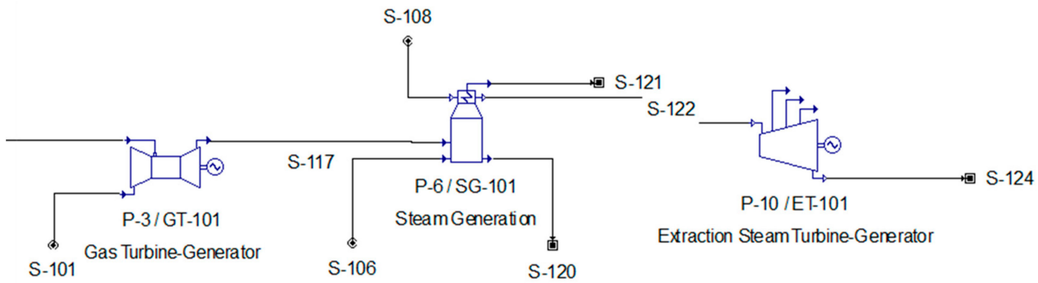

Figure 3. Process flow diagram of the CHP in SuperPRO Designer.

In the biogas production stage, the equipment for a CHP unit is similar for the three different types of feedstock. Table 4 shows the technical operation parameters of the CHP unit and Table 5 presents the input and output data of the CHP unit for each feestock. The electricity generated in the gas turbine-generator and steam turbine-generator can be sold. The current electricity price set on the market is 0.11 €/kWh [62]. It is stated that a subsidy of 20 €/MWh is added [63].

Table 4. Main parameters used for modeling the CHP unit used in the feedstocks CM, SBP, and GS.

Unit ID	Description	Details	CM	SBP	GS
P-17/G-101	Gas compressor	Compressor power (kW)	13.1	32.8	37.1
P-3/GT-101	Gas turbine-generator	Electrical power (kW)	441.2	1105.2	1249.5
P-6/SG-101	Steam generator	Throughput (kg/h)	540.3	1239.7	1401.8
P-10/ET-101	Extraction steam turbine-generator	Turbine delivered shaft power (kW)	27.0	85.7	100.4

Therefore, the revenue that is generated by a CHP unit is 0.13 €/kWh. All the steam that is generated via the steam generator is used in the AD. Therefore, the assumption is made to set the cost of steam at 0 €/ton. Biogas, water, and air are used to produce electricity and steam. The difference in volume can be explained by the amount of biogas being treated.

Table 5. The input and output of the CHP unit for the feedstocks CM, SBP, and GS.

Unit ID	Input	Volume (kg/h)		
		CM	SBP	GS
S-111	Biogas	156.4	391.8	442.8
S-108	Water	640.3	1293.7	1401.8
S-101	Air	4191.7	10,500.7	11,872.3
	Output			
S-124	Steam	520.3	1239.7	1401.8
S-110	Residues	4348.1	10,892.4	12,315.0

2.2.3. Digestate Treatment

A pump is used to transport the digestate from the anaerobic reactor towards the screw pressing (Figure 4). Table 6 shows the composition of digestate of the AD of the different types of feedstock before the screw pressing process.

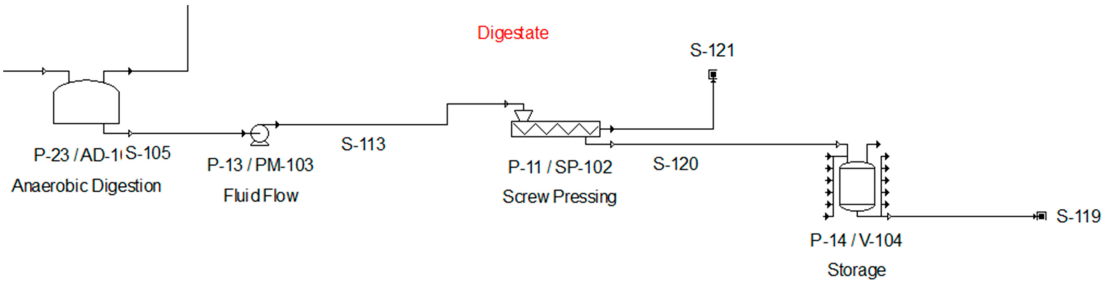

Figure 4. Process flow diagram of the digestate processing in SuperPRO Designer.

The selling price of the digestate as fertilizer after the screw pressing process is obtained from literature and is 70.95 €/ton [64]. It is assumed that all the digestate that is produced during the year is sold. Both in the biogas production stage as in the digestate stage, the equipment for every type of feedstock is the same. However, the equipment costs vary due to the volumes being treated. Table 7 shows the main parameters used for the simulation of digestate processing.

Table 6. The composition of the digestate (wet weight) from anaerobic digestion of CM, SBP, and GS.

Ingredient	CM	SBP	GS
	Mass %	Mass %	Mass %
Ash	2.38	5.83	10.77
Cellulose	1.48	8.70	18.15
Hemicellulose	1.09	10.45	15.50
Lignin	1.23	0.49	13.86
Lignin soluble			2.18
Proteins	0.25	5.92	-
Extractives	2.21		12.05
Water	90.85	43.35	24.44
COD eq.	0.12	0.33	0.48
Sludge	0.34	0.98	1.41
Fats	0.07		

The rate of dewatering the digestate obtained from the anaerobic digestion of CM, SBP, and GS is shown in Table 8. Due to the water content of the initial feedstocks, the yield of residues from GS is higher compared to the other type of feedstocks.

Table 7. Main parameters used for simulation of the digestate processing obtained after the anaerobic digestion of the feedstocks CM, SBP, and GS.

Unit ID	Description	Details	CM	SBP	GS
P-13/PM-103	Centrifugal pump	Power pump (kW)	0.01	0.03	0.03
P-11/SP-102	Screw pressing	Throughput (kg/h)	337.3	852.0	801.0
P-14/V-104	Receiver tank	Vessel volume (L)	3105.9	14,324.5	17,686.5

Table 8. Input and output from the digestate processing stage.

Unit ID	Input	Volume (kg/h)		
		CM	SBP	GS
S-106	Digestate	337.3	852.0	801.0
	Output			
S-121	Water	192.8	266.3	4.5
S-129	Residues	143.5	585.7	796.5

2.3. Economic Evaluation

SuperPro Designer simulator is used design the plant equipment and evaluate the different costs of heat and power generation. For the economic assessment, the plant cost (PC) is calculated by adding the total plant indirect cost (TPIC) with the total plant direct cost (TPDC). The TPDC includes equipment purchase costs, installation costs, process piping, instrumentation, electrical, building, yard improvement, and auxiliary facilities costs. The TPIC includes engineering and construction costs. Furthermore, the contractor's fee and contingency are calculated as 6% and 8% of the plant cost (PC) [65].

The direct fixed capital cost of the plant is calculated by adding the PC and contractor's fee and contingency (CFC). It is assumed that the plant lifetime is 25 years and operates 335 days a year. During the 335 days of operation, the plant operates at full capacity. The construction time is assumed to be 12 months, with a startup period of 4 months [64]. The year that the construction of the plant starts is 2019 and the inflation, to update the equipment cost, is 4%. The interest rate is set at 5%. The main annual operating cost includes labor, facility, and utility costs. It is assumed that GS is free and is not included in the annual operating costs. The transportation costs of feedstock is assumed €3.50/ton for an average shipping distance of 50 km. Moreover, it is assumed that the direct labor costs are €22/h and the indirect labor costs €7.90/h. It is assumed that two operators are needed to run the biogas plant. In Table 9, the assumptions used to estimate the annual operating costs are shown. The data is acquired from the SuperPro designer database and literature [65].

Table 9. Assumptions used to model the annual operating cost.

Parameters	Assumptions
Material costs	
Cow manure	0 €/kg
Sugar beet pulp	0.0105 €/kg
Grass straw	0 €/kg
Utility costs	
Std power	0.09 €/kWh
Steam	11.28 €/MT
Steam for CHP	0 €/MT
Cooling water	0.05 €/MT
Chilled water	0.38 €/MT

Table 9. *Cont.*

Parameters	Assumptions
Labor costs	
Labor price	29.90 €/h
Facility costs	
Maintenance	0.02 × TPDC
Depreciation	Straight-line method
Insurance	1.00 × TPDC
Tax	0.02 × TPDC
Factory expense	2.50 × TPDC

3. Results

3.1. Equipment Costs

Table 10 shows the total equipment costs used in the design of a biogas power plant using CM, SBP, or GS as feedstock. The most expensive equipment is the anaerobic reactor, which forms around 37–42% of the total equipment costs. The main differences in the total costs can be explained by the fact that the gas turbine-generator is more expensive when more electricity is generated.

Table 10. Equipment costs of a biogas power plant.

Type of Feedstock	Total eq. Costs (€ × 10^3)
CM	1531
SBP	2425
GS	2486

3.2. Fixed Capital Costs

The fixed capital cost is dependent on the total purchasing price of the equipment. The previous subsection showed that the equipment cost of SBP and GS are higher compared to CM and results in higher fixed capital costs. In Table 11, the direct fixed capital cost (DFC) of the biogas power plant treating CM, SBP and GS are shown.

Table 11. Summary of fixed capital costs of biogas power plant.

Type of Feedstock	TPDC (€ × 10^3)	TPIC (€ × 10^3)	CFC (€ × 10^3)	DFC (€ × 10^3)
CM	4483	2690	1004	8177
SBP	7071	4243	1584	12,898
GS	7289	4373	1633	13,295

3.3. Labor Costs

The total labor cost is 29.90 €/h. It is assumed that the labor hours are similar for all the cases. Therefore, the labor costs are equal to 131,544 € for each case.

3.4. Annual utility and operating costs

Electricity, steam and cooling water are the utilities required in the biogas power plant process. The steam costs are set at 0 €/MT. The other unit costs are set by the database from SuperPro Designer. Table 12 shows the annual utility and operating costs of a biogas power plant.

Table 12. Annual utility and operating costs of the biogas power plant.

Type of Feedstock	Annual Utility Costs (€ × 10^3)	Annual Operating Costs (€ × 10^3)
CM	20,082	715
SBP	49,941	1162
GS	53,784	1086

The annual operating costs of the biogas plant treating CM is lower than those of SBP and GS. In addition, the difference between the annual operating costs of SBP and GS is possibly attributed to the purchasing price of SBP.

3.5. Revenues

The main revenues of the biogas power plants are the electricity generated from the gas turbine-generator and the steam turbine-generator. The digestate forms another important income source and can significantly influence the total revenues. Tables 13 and 14 show the total revenues, with the assumption that all the outputs are sold, excluding and including a subsidy. As can be concluded from Tables 13 and 14, the green-energy subsidy increases the annual revenues for CM, SBP, and GS by 70,942 €, 177,712 €, and 200,918 €, respectively. The revenue of CM received from farmers is an important income source and forms around 38% of the total revenues. In the case that subsidy is added to the electricity selling price, the revenue received from farmers forms around 34% of the total revenues of the biogas power plant treating CM.

Table 13. Revenues (€) per year of a biogas power plant excluding subsidy.

Stream	CM (€)	SBP (€)	GS (€)
Gas Turbine-Generator (P-3)	390,180	977,419	1,105,044
Steam Turbine-Generator (P-10)	21,472	68,198	79,928
Digestate (S-119)	81,799	333,883	454,051
Feedstock	300,005		
Total	793,456	1,379,500	1,639,024

Table 14. Revenues (€) per year of a biogas power plant including a subsidy of 20 €/MWh.

Stream	CM (€)	SBP (€)	GS (€)
Gas Turbine-Generator (P-3)	461,122	1,155,131	1,305,962
Steam Turbine-Generator (P-10)	25,376	80,598	94,460
Digestate (S-119)	881,799	333,883	454,051
Feedstock	300,005		
Total	868,302	1,569,612	1,854,473

3.6. Viability

Tables 15 and 16 show the executive summary of the viability of the biogas power plants, without and with a subsidy. The conclusion from Tables 15 and 16 is that the subsidy for electricity does not change the feasibility of the plants in case that CM or SBP are used as the feedstock.

Table 15. Viability of biogas power plant excluding subsidy.

Stream	CM	SBP	GS
Total Capital Investment (€ × 10^3)	8599	12,937	13,325
Capital Investment Charged to this Project ((€ × 10^3)	8599	12,937	13,325
Operating Costs (€ × 10^3/yr)	715	8599	1086
Total Revenues (€ × 10^3/yr)	793	8599	1693
Gross Margin (%)	9.85	15.77	33.76
Return On Investment (%)	5.06	5.75	7.23
Payback Period (years)	19.75	17.41	13.83
IRR (%)	1.80	2.58	5.23
NPV (at 5.0% Interest) (€ × 10^3)	−2076	−2467	192

The NPV of biogas plants using CM and SBP is negative. The subsidy is not sufficient to obtain a positive NPV of the two plants treating CM or SBP. The biogas power plant treating GS shows a positive NPV even without subsidy, which means that it is more desirable to invest in a plant that produces electricity and digestate from GS.

Table 16. Viability of biogas power plant including subsidy.

Stream	CM	SBP	GS
Total Capital Investment (€ × 10^3)	8599	12,937	13,325
Capital Investment Charged to this Project ((€ × 10^3)	8599	12,937	13,325
Operating Costs (€ × 10^3/yr)	715	1165	1086
Total Revenues (€ × 10^3/yr)	868	1570	1854
Gross Margin (%)	17.62	25.98	41.45
Return On Investment (%)	5.58	6.63	8.20
Payback Period (years)	17.91	15.02	12.19
IRR (%)	2.89	4.14	6.64
NPV (at 5.0% Interest) (€ × 10^3)	−1452	−881	1935

To find out how a ± 5–10% change in decision parameters may affect the profitability, a sensitivity analysis is performed. In the analysis the following parameters are included: the price of electricity, interest rate, conversion factor of hemicellulose and cellulose, price of digestate and for the biogas power plant treating CM the price of CM is added. The electricity price and the interest rate play a significant role in the NPV of the biogas power plant treating CM, SBP, and GS. Figure 5 shows the sensitivity analysis of a biogas power plant treating CM including the subsidy added to the electricity price.

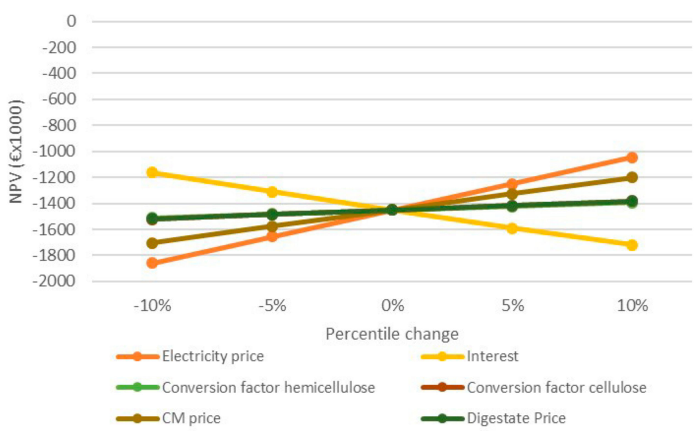

Figure 5. Impact of ±5% and ±10% change of the parameters on the profitability of a biogas power plant that uses CM as feedstock.

It can be seen that a change in the conversion factor of hemicellulose and cellulose has the lowest impact on the NPV. The slope of the electricity price is the steepest, indicating that an increase in electricity price causes the largest increase in NPV. However, if all parameters increased with a factor of 10% the feasibility of a biogas plant treating CM is not reached.

Figure 6 shows that an increment of the electricity price by 10% results in a positive NPV for the biogas power plant treating SBP. The biogas power plant treating GS is the most secure investment. A 10% decrease in electricity price or in any of the other parameters still yields a positive NPV (Figure 7).

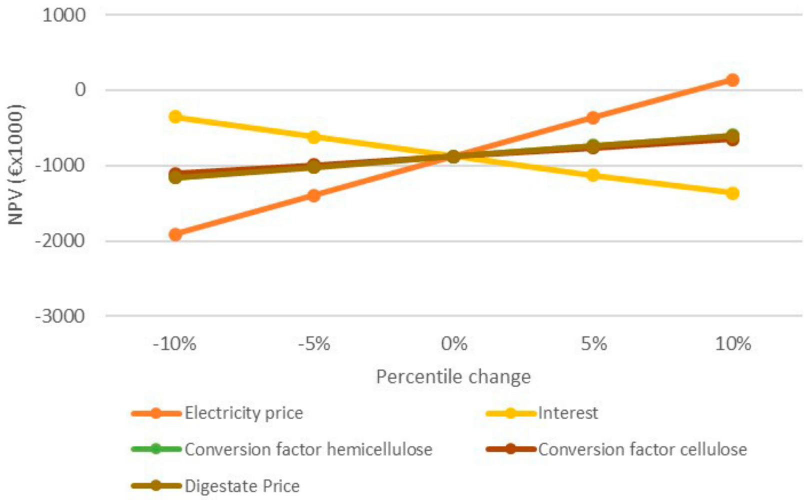

Figure 6. The influence of ±5% and ±10% change of the parameters on the profitability of a biogas power plant that uses SBP as feedstock.

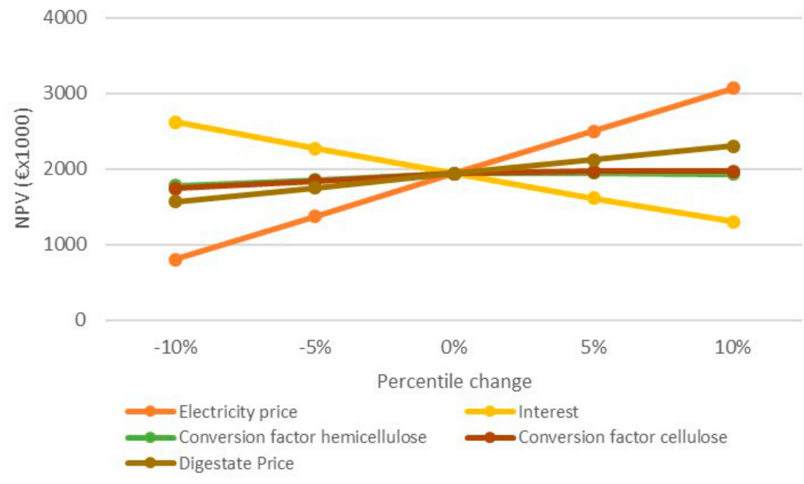

Figure 7. The influence of ±5% and ±10% change of the parameters on the profitability of biogas power plant that use GS as feedstock.

4. Conclusions

Process design was facilitated to investigate the viability of the biogas power plant. Specific process parameters and critical factors were discussed. However, some uncertainties may affect the results. The plant was designed with the SuperPro Designer software, and the treatment of three different types of lignocellulosic feedstock was investigated. CM, SBP and GS were selected to use as input since these types are widely available in agro-industrial regions. The plant treating SBP showed negative NPV of -881×10^3 €, however, there are factors that can improve its viability. Only the plant treating GS resulted in an NPV of 192×10^3 € and 1935×10^3 € without and with subsidy respectively. The results showed that a biogas power plant treating GS or SBP can be a solution for the bioenergy sector when subsidies are included. Furthermore, GS is the most profitable feedstock compared to the other types.

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Abbreviations

AD	anaerobic digestion
CFC	contractor's fee and contingency
CHP	combined heat and power
CM	cow manure
EU	European Union
GHG	greenhouse gases
GS	grass straw
IRR	internal rate of return
NPV	net present value
MT	mega ton
PC	plant cost
SBP	Sugar beet pulp
TPDC	total plant direct cost
TPIC	total plant indirect cost

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